FIRE AS AN ECOLOGICAL FACTOR

IN NORTHEASTERN MINNESOTA

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I. INTRODUCTION

Research during the past four decades has shown that fire is a natural agent which has been shaping the composition and boundaries of forests and prairies long before the appearance of modern man in such areas. In America, Indians often set fires for purposes such as driving game, clearing forest underbrush and prairie farmland, obtaining firewood, signaling, controlling insects, and increasing the berry crop (Ahlgren and Ahlgren, 1960).

Failure to recognize that ecosystems may be fire-adapted has resulted in management practices that threaten the balance of living organisms within such ecosystems. Odum (1971) includes fire as an important limiting factor along with other agents such as water, light, moisture, and air.

Two extreme types of forest fires are crown fires and surface fires. The former often destroys all vegetation and may consume humus so as to expose mineral soil. Surface fires can move through groves of mature trees without noticeably damaging them, eliminating some components of the understory and creating favorable conditions for the development of others. Light surface fires often reduce the flammability of the forests, speeding the decay process, and creating a seedbed favorable for the reseeding of species requiring lesser humus accumulation.

Scientists and the public have regarded fire as a destructive, wholly negative event which is to be avoided at all costs. Reversing such prejudices has generally progressed well enough among scientists, and the relatively young area of study known as fire ecology now has many disciples. Recent events in certain National Parks suggest that the public, given the facts and concepts, is willing to accept the current views regarding the importance of fire.

The first project to include the use of wildfire as a management tool on National Forest lands was initiated in 1972 for a portion of the Selway-Bitterroot Wilderness (SBW) of northern Idaho and western Montana (Aldrich and Mutch, 1972). Under this policy, fire control is brought into operation when fires threaten to cross the boundary of the study area and when fire danger rating is high. Extensive investigations in plant ecology indicate that the vegetational composition of the SBW is showing characteristics which threaten the continued existence of the highly diversified vegetation of this region, due to the fire control policies effective since the 1930's (Habeck, 1972).

The purpose of this paper is to investigate the nature of the role of fire in northeastern Minnesota, regarding its influence primarily on vegetation. Paleobotanical research in the Boundary Waters Canoe Area (BWCA) and study of vegetational characteristics provide a history of fire and plant cover for certain areas of northeastern Minnesota.

II. FIRE AND VEGETATIONAL HISTORY OF THE BWCA

A. Paleobotanical research

The vegetational and fire history of the past 10,000 years has been investigated in studies involving analysis of pollen and charcoal from sediment cores taken from the Lake of the Clouds, a small but deep lake in the BWCA (Craig, 1972 and Swain, 1972, 1973). Airborne debris from local forest fires settled into the lake, forming charcoal layers corresponding with those fires. The sediment of this lake is laminated such that annual pollen layers (varves) can be identified for the past 9,500 years. Cores of sediment were analysed for dating and identification of annual pollen layers and for charcoal content, an indication of forest fires in the area.

The charcoal samples and pollen varves show that fire has been an important factor in determining the composition of the forest mosaic in the vicinity of this lake during most of its past-glacial history. Climatic changes and resulting variations in vegetation for the Lake of the Clouds have been discussed by Craig (1972).

Climatic conditions influence the vegetational composition and one way by which this influence is rendered is through the relative frequency of fire. Figure 1 shows the charcoal influx values generally represent the changing climatic conditions. From 9000 to 6000 y.a. the charcoal levels remain fairly high, corresponding with a warming trend which reached a peak about 7000 - 6000 y.a. (Craig,

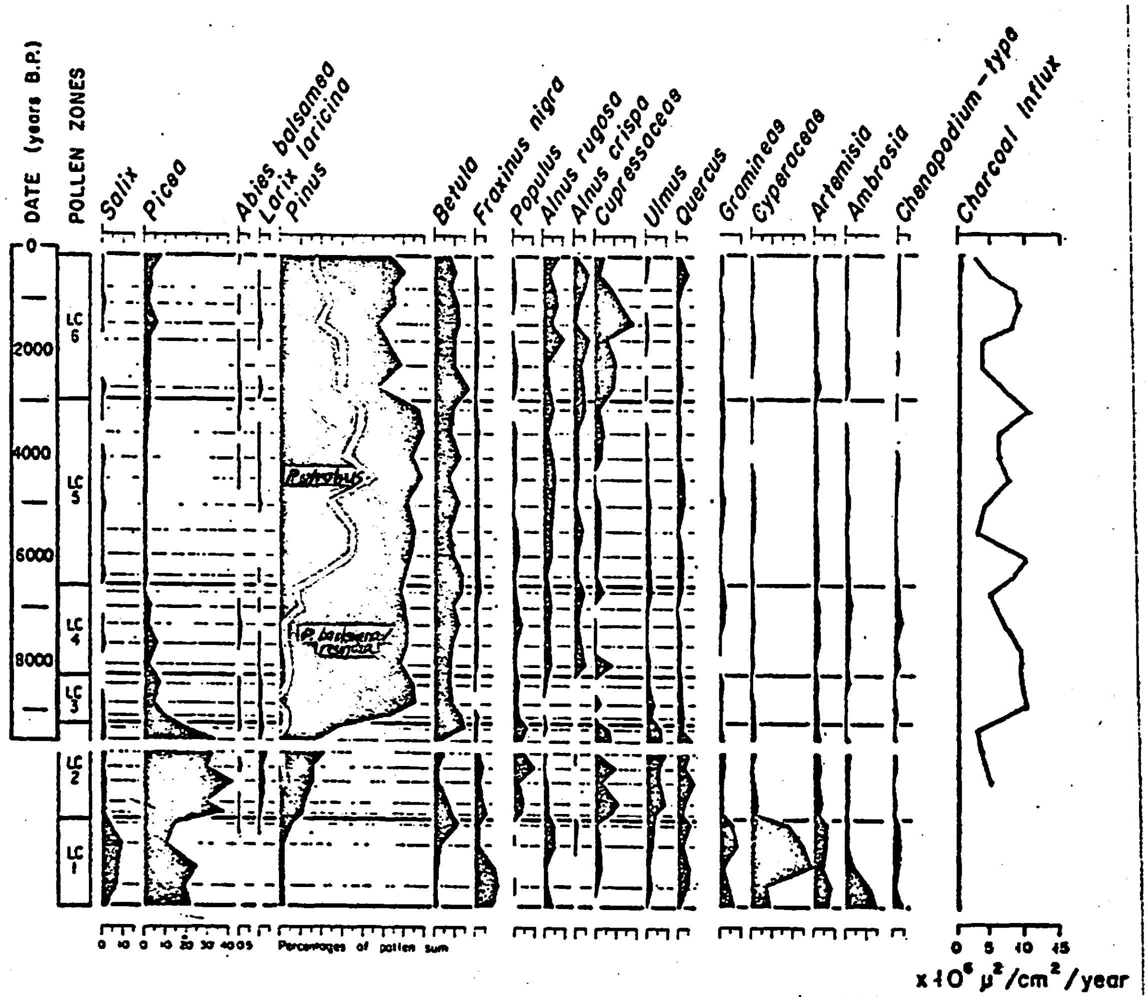


FIG. 1. Percentage diagram of selected pollen types at Lake of the Clouds (Craig, 1972), with the charcoal influx curve added. (From Swain, 1973)

1972 and Swain, 1973). By 6000 y.a. white pine (P. strobus) has become more common than red pine (P. resinosa)and jack pine (P. banksiana). The charcoal influx shows a sporadic, generally lessened occurrence of fires from about 6000 to 3000 y.a. (Zone 5), during which time the pollen types remain relatively stable with the exception of a decrease in pine pollen. Climatic cooling of the past 3000 years (Zone 6) is indicated by the increasing percentage of spruce (Picea spp.) and alder (Alnus spp.) and the decreasing values of white pine. From about 3000 to 1200 y.a. the decreased charcoal levels correspond to a lessened influx of total pine pollen and an increase in white cedar (Cupressaceae). A reversal of the trend occurs around 1200 y.a. (For further discussions of post-glacial climatic conditions, refer to Frenzel, 1966; Cushing, 1965; and Fries, 1962.)

Studies of lake sediments thus show fire as a part of the natural environment of the BWCA for at least 9,000 years. Work in fire history "on the ground" can provide precise information only for the past few hundred years.

Figure 2 presents data obtained from sediment cores respresenting the past 1000 years of fire and vegetation history of the Lake of the Clouds (Swain, 1973). The increase in varve thickness of the last century may be a result of those layers not having been compressed over a long period of time as have older laminations. The declining charcoal influx values since 1920 were most likely caused

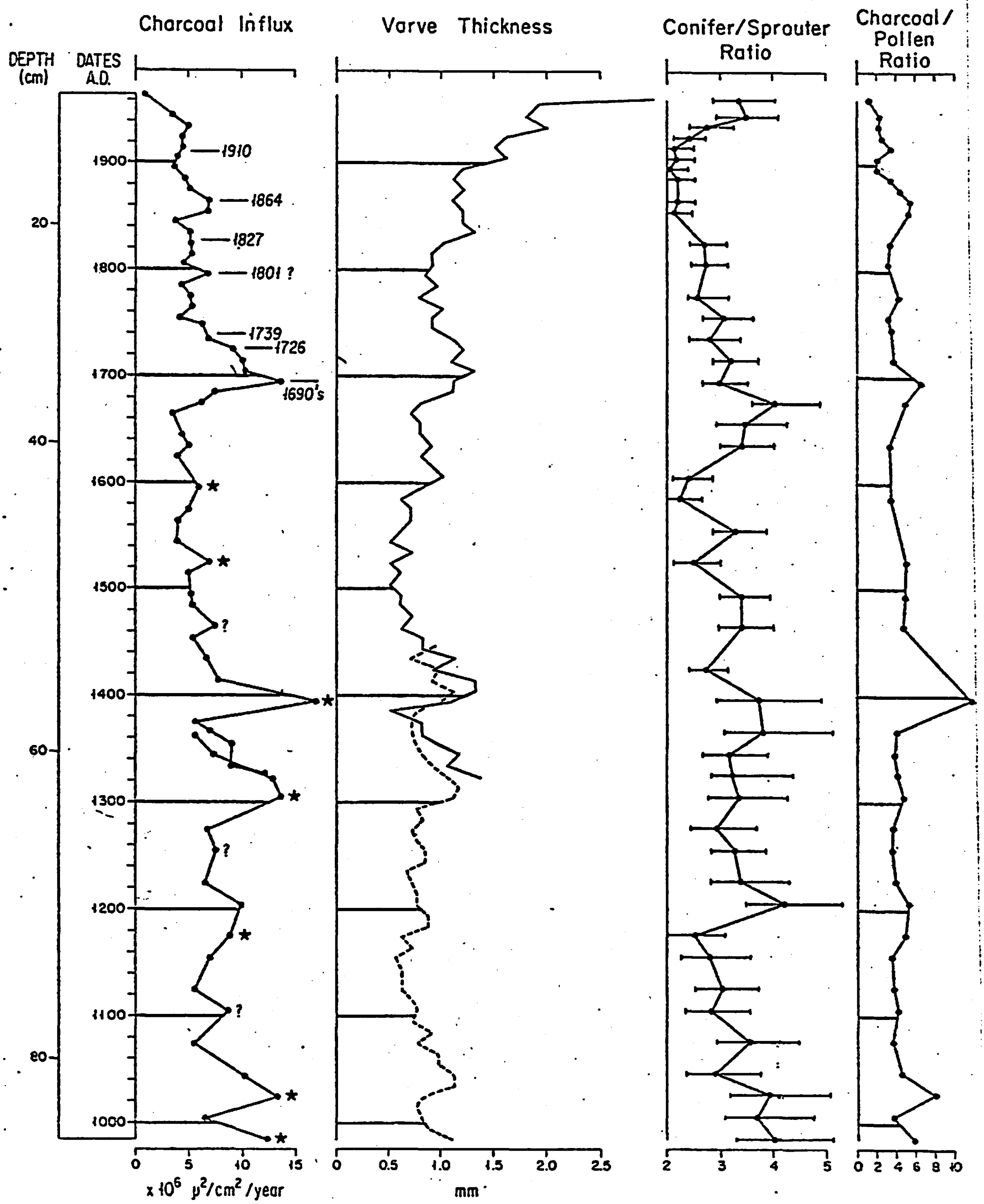


FIG. 2. Charcoal and pollen influx into Lake of the Clouds over the past 1,000 years. (Adapted from Swain, 1973)

by disturbance of the uppermost sediment layers by the core sampling tube. The increase of ragweed (Ambrosia) pollen after 1890 probably resulted from agricultural activities southwest of the BWCA. A lesser influx of white pine pollen since 1910 may have been caused by a combination of several factors, such as logging, white pine blister rust, and the fire of 1910. The chronology of historically known local fires is indicated in the charcoal influx curve. Asterisks mark the combination of increased varve thicknesses and charcoal peaks which indicate pre-eighteenth century local fires. Charcoal peaks not correlated with greater varve thickness are marked by ? on Figure 2.

Two parameters for interpreting sediment core data are the charcoal/pollen ration and the conifer/sprouter ratio (Fig. 2). Influx values and varve thickness measurements may give anomolous peaks - i.e., peaks indicating local fires when no supporting evidence of fire can be found. This may be caused by small errors in varve - counting and by erosion and redeposition of sediment within the lake basin to produce elongated or even false peaks. The ratio of charcoal to pollen tends to eliminate false peaks and may indicate known fire activity, e.g. the 1910 fire, that otherwise may not be indicated by the data. Vegetation response to periodic burns may be shown by the ratio of conifers to sprouters (Fig. 2). Population increases of sprouters following local fires tend to decrease the

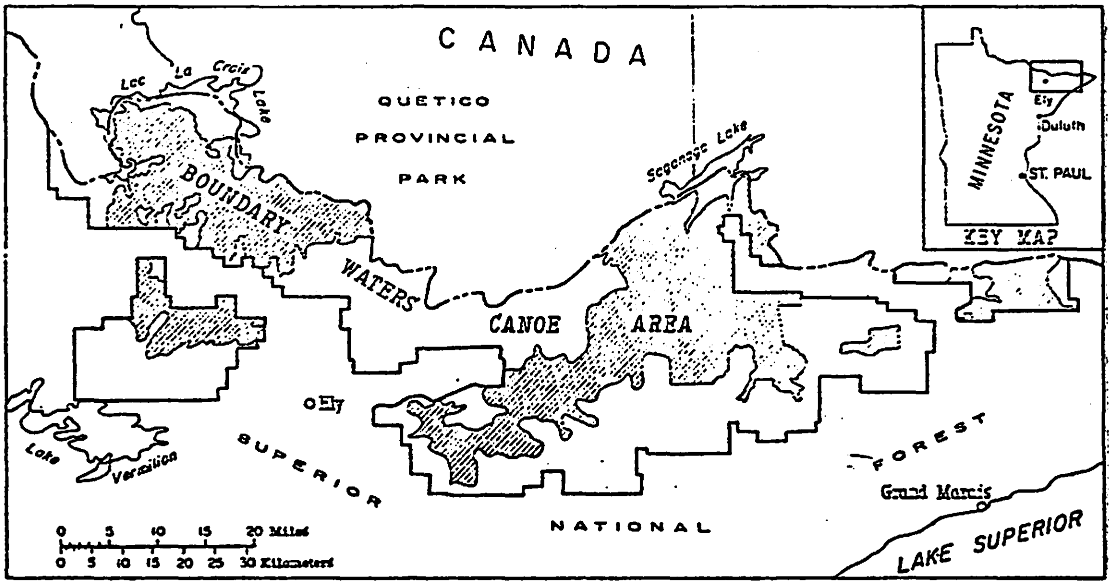


FIG. 3. Location of study area (bounded by heavy line) and of the remaining virgin forests of the Boundary Waters Canoe Area (shaded area). (From Heinselman, 1973)

conifer/sprouter ratio. Increasing ratio values indicate a maturing forest, as conifers reach seed-bearing age and gradually replace the sprouters. The pollen types represented in the ratio are listed below (Swain, 1973).

Conifers	Sprouters
Pinus banksiana/resinosa	Gramineae
P. strobus	*Betula*
Picea	*Populus*
Abies	*Alnus*
Larix	*Corylus*
Cupressaceae	*Pteridium*

The average fire frequency in the Lake of the Clouds area for the past 1000 years is about 60-70 years, with a range of about 20-100 years. The periodic fires have caused short-term vegetational changes but kept the major pollen types relatively stable. Based on these studies, Swain (1973) concluded that fire in the BWCA is necessary to perpetuate the present vegetation types.

Work such as the Lake of the Clouds project and other sedimentation analysis using material from peat bogs and other lakes show that fire was a component of the northeastern Minnesota environment for thousands of years before white men arrived. The extent of forest fires, both deliberate and accidental, set by Indians in this area is not known. In other forested areas of North America, Indians used fires extensively for driving wildlife, clearing the forest of underbrush, and obtaining firewood (Lutz, 1956;

FIG. 4. Areas known to have been burned by significant forest fires in the Boundary Waters Canoe Area and vicinity, 1610-1972 A.D., based on stand origin maps, field evidence, and historical records. Shaded areas show general areas burned by fires of indicated years. (From Heinselman, 1973)

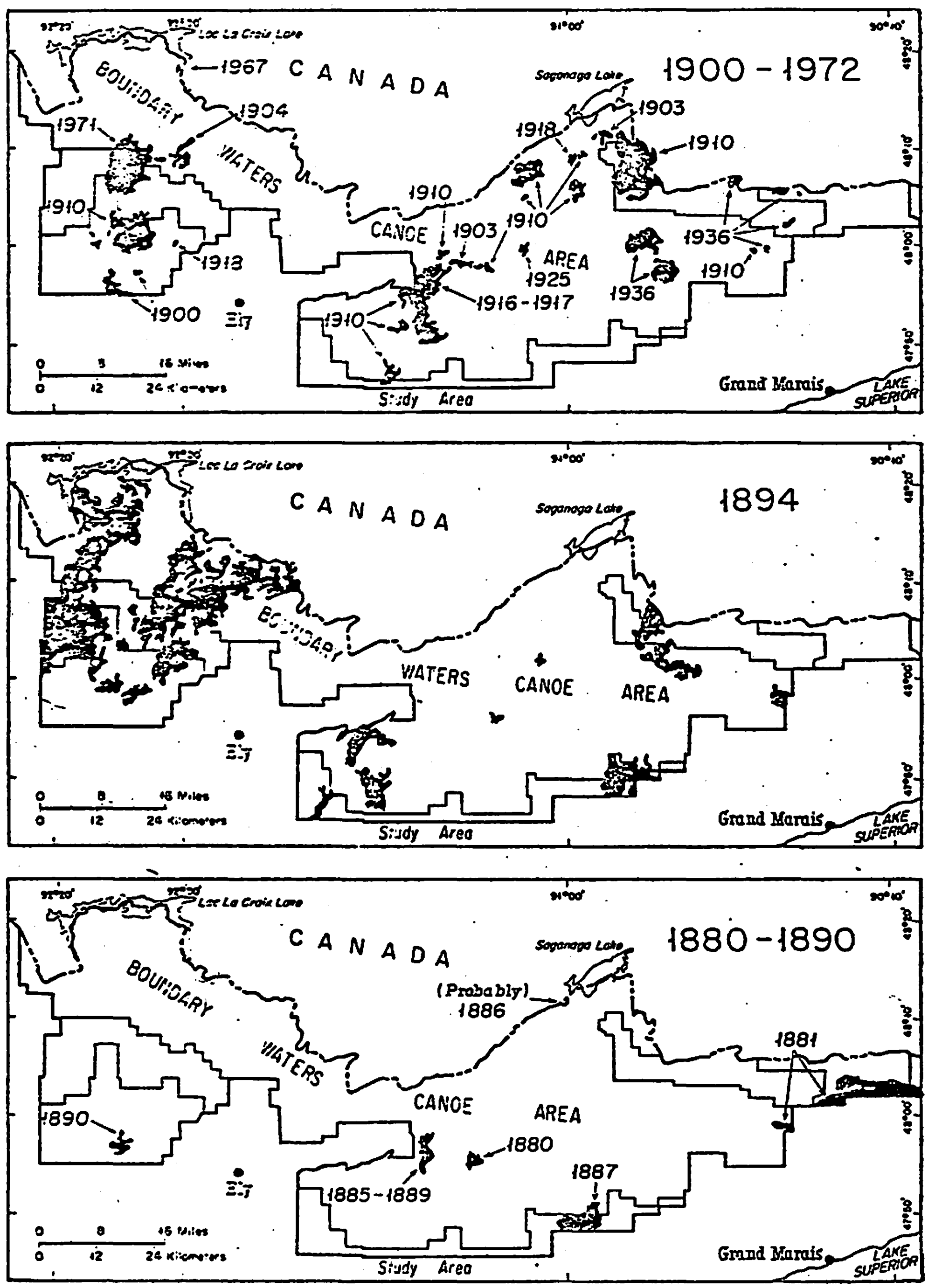
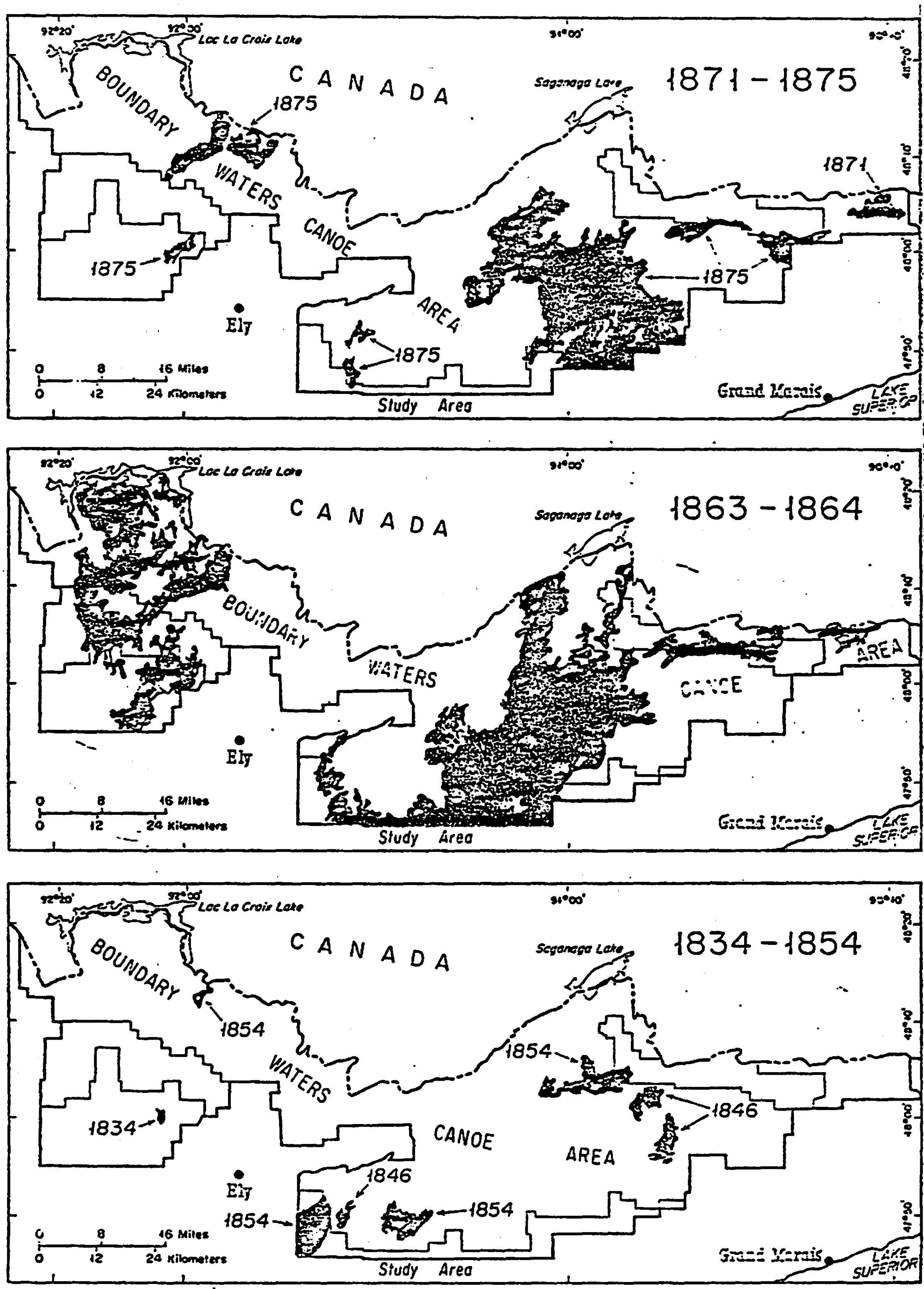


FIG. 4, con'd.



Lac La Croix Lake
CANADA
Saganaga Lake
1871 - 1875
BOUNDARY
WATERS
CANOE
AREA
1875
1871
Ely
0 8 16 Miles
0 12 24 Kilometers
Study Area
Grand Marais
LAKE SUPERIOR
1863 - 1864
1834 - 1854
1854
1834
1846

FIG. 4, con'd.

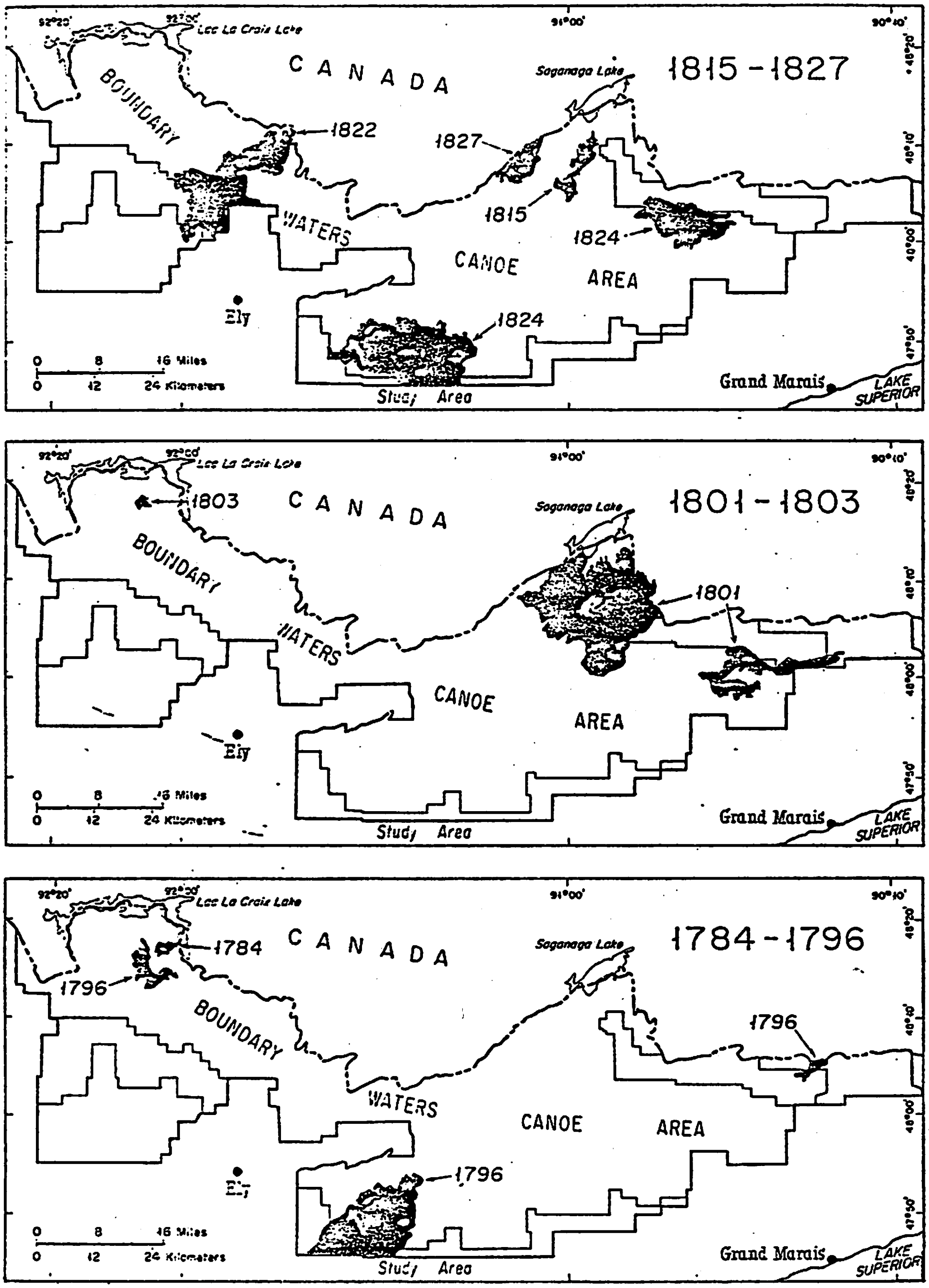
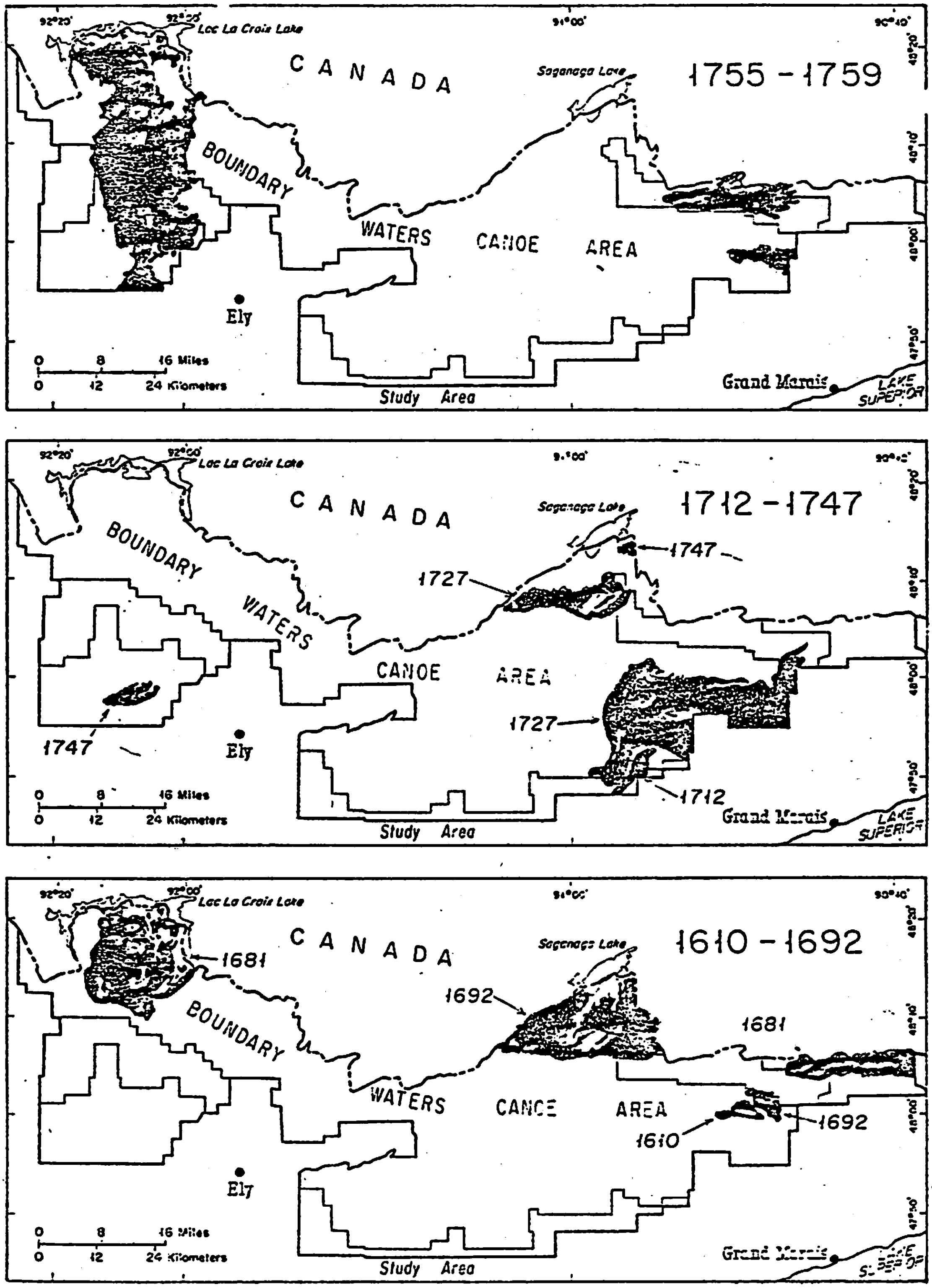

1815-1827
CANADA
BOUNDARY
WATERS
CANOE
AREA
Lac La Croix Lake
Saganaga Lake
1822
1827
1815
1824
1824
Ely
Study Area
Grand Marais
LAKE SUPERIOR
0 8 16 Miles
0 12 24 Kilometers
1801-1803
1803
1801
1784-1796
1784
1796
1796
1796

FIG. 4, con'd.



92°20'
92°00'
Lac La Croix Lake
CANADA
Saganaga Lake
1755 - 1759
BOUNDARY
WATERS
CANOE
AREA
Ely
0 8 16 Miles
0 12 24 Kilometers
Study Area
Grand Marais
LAKE SUPERIOR
92°20'
92°00'
Lac La Croix Lake
CANADA
Saganaga Lake
1712 - 1747
1747
1727
BOUNDARY
WATERS
CANOE
AREA
1747
1727
1712
Ely
0 8 16 Miles
0 12 24 Kilometers
Study Area
92°20'
92°00'
Lac La Croix Lake
CANADA
Saganaga Lake
1610 - 1692
1681
1692
1681
BOUNDARY
WATERS
AREA
1692
1610
0 8 16 Miles
0 12 24 Kilometers
Study Area

Thompson and Smith, 1970). In Itasca State Park in northern Minnesota, cones and fire-charred wood of jack pine and black spruce found in glacial drift were dated by ^{14}C technique as more than 38,000 years old (Heinselman and Roe, 1963).

B. 1595 A.D. to the present

Extensive work to elucidate the fire history of the BWCA has been conducted by Heinselman (1971, 1973). The study area consisted of 1.3 million acres which included the entire BWCA and some adjacent land (Fig. 3). The net land area of the BWCA which has not been disturbed by cutting is approximately 415,000 acres. Methods used to obtain this history for about the past 370 years included the following:

a) reviewing historical documents, maps, government reports, and General Land Office survey notes

b) obtaining the ages of thousands of over-story trees throughout the virgin forests by means of increment borings

c) dating of fire-scars by counting annual rings from the cambium to the scars

d) mapping of forest age classes and fire boundaries

e) studying the age structure and reproductive characteristics of tree species in the area

From these data, fire year maps of the entire study area (Fig. 4) and stand origins of the virgin forest areas (Table 1) were constructed. Heinselman (1973) cautions that the fire data may be conservative, due to the short-term evidence left by light ground fires and by repeating and overlapping fires. The record dates from 1595 A.D., the apparent origin of the oldest living stand, a group of red pines on Three Mile Island in Seagull Lake.

The geographical boundaries of significant fires are presented on the fire year maps (Fig. 4). The map of 1900-1972, in comparison with those maps showing the previous fire history, clearly shows the effect of twentieth century fire prevention upon the occurrence of forest fire in the entire study area. Within the virgin forest area, only about 12% of the stands originated following fire since 1900, whereas about 72% of the stands date back to 1830-1900 (Table 1).

Based upon the fire history since 1595 A.D., Heinselman (1973) calculated that the average interval between "major fire years" (burning more than 100 square miles = over 6% of the area) is 28 years. Burns during these major fire years account for most fire activity and the subsequent forest rejuvenation. 73% of all remaining virgin stands in the BWCA date from 5 years: 1863, 1864, 1875, 1894, and 1910 (Table 1).

In the drought years of 1863-1864, over 40% of the study area burned (Fig. 4). With the present intensive use of this area by man, a conflaguration of such proportions would be disastrous. Yet fire prevention and the build-up of fuel may be creating conditions that, given such weather conditions as low precipitation, high temperature, and wind, may lead to such an event.

Table 1. Virgin forest areas of the BWCA by stand origin years, March 1973[1] (land areas only). (From Heinselman, 1973)

Stand origin year	Area in 1973	Percent of total	Cumulative percent of total
	Acres		
1971	2032	0.5	0.5
1967	128	—	.5
1936	7968	1.9	2.4
1925	400	.1	2.5
1918	576	.1	2.6
1917	1856	.4	3.0
1914	32	—	3.0
1910	34,000	8.2	11.2
1904	1952	.5	11.7
1903	2368	.6	12.3
1900	512	.1	12.4
1894	96,944	23.2	35.6
1890	32	—	35.6
1889	256	.1	35.7
1887–8	176	.1	35.8
1885–7	384	.1	35.9
1882	288	.1	36.0
1881	9968	2.4	38.4
1875	90,614	21.8	60.2
1871	5856	1.4	61.6
1863–4	83,600	20.1	81.7
1854	8112	2.0	83.7
1846	2656	.6	84.3
1827	912	.2	84.5
1824	1616	.4	84.9
1822	6128	1.5	86.4
1815	5200	1.3	87.7
1803	176	.1	87.8
1801	17,072	4.1	91.9
1796	5840	1.4	93.3
1784	432	.1	93.4
1766	48	—	93.4
1755–9	12,240	2.9	96.3
1747	768	.2	96.5
1739	160	—	96.5
1727	3408	.8	97.3
1712	240	.1	97.4
1692	1472	.4	97.8
1681	8560	2.0	99.8
1648	64	—	99.8
1610	720	.2	100.0
1595	16	—	100.0
Total	415,782	100.0	100.0

[a] Virgin areas are those never logged, cleared, roaded, etc. Essentially *all* areas have burned since 1595 A.D. Stand origin years are the year of the last major fire from which the *overstory* dates. Many stands established prior to 1900 have been burned through one or more times without total overstory kill. For such stands the year given is the year of the fire from which the *overstory* dates, even though there may be significant stand elements dating from later fires.

III. THE EFFECTS OF FOREST FIRE ON TREES

A. Forest composition

Many tree species of the northern coniferous forests possess characteristics which enable them to be successful fire-following pioneer species. Several conifer species, also broadleaf species such as aspen and birch, exhibit such adaptations. Large forest areas left to natural controlling factors are rarely of uniform composition. Fire, insects, and topographical features dictate that a large forest area is a mosaic of many smaller areas of varied composition and stages of development. Stability as applied to the forest mosaic refers to continuation of the variety of cover types. In the abscence of controlling factors, variety gives way to uniformity with the development of climax communities. Stability in this context, implies the perpetuation of species rather than the perpetuation of stands.

Fire has been a major ecological force for thousands of years, shaping the forest mosaic and rendering it stable over those years. The long association of fire and forests has resulted in forests largely composed of fire-adapted species in areas subjected to periodic fires. Some species are virtually dependent upon fire for competitive regeneration.

Each species possesses unique characteristics which insure its survival in a fire regime. This section deals with silvical characteristics of individual species pertinent to their success in such an environment. From germination to maturity, fire at some time affects the establishment and survival of these species. Data obtained in northeastern Minnesota are used when available. Studies from other locations in the boreal forest zone are included. Interior Alaska has been the site of much work with forest fire ecology and the silvics of native tree species of the boreal zone. Zasada (1971) presented data compiled from numerous sources, which involve reproductive characteristics of fire tree species in the Alaskan interior (Table 2). Four of these species are major components of plant communities of northeastern Minnesota.

Favorable effects of forest fire upon tree establishment include the physical effects of removing layers of dry organic matter so that the short initial root system of conifers, especially pines, can reach the more moist climate of mineral soil (Ahlgren and Ahlgren, 1960). Burning releases nutrients that otherwise would be bound in the organic layer. Fire also provides openings for the establishment of shade-intolerant species.

B. Jack pine (*Pinus banksiana*)

Jack pine is frequently referred to as a fire following species of the northern forest. The presence of the serotinous cone, the requirement of seedlings for the micro-environment produced by a herbaceous cover, and exposure of mineral soil for germination are some characterics which

Table 2. Seed, seedbed, and vegetative reproduction variables for white spruce, black spruce, paper birch, quaking aspen, and balsam poplar in interior Alaska. (From Zasada, 1971)

Variable	White spruce	Black spruce	Paper birch	Quaking aspen	Balsam poplar	Summary and ranking by species
Seed production-tree age relationship in natural stands:						
First abundant production	About 40 yrs.	24 yrs.	15 yrs.*	20 yrs.*	*	Earliest to latest Birch > aspen ≧ poplar > black spruce > white spruce
Period of optimum production	40 to 170 or more yrs.	24-194 or more yrs.	45-100 yrs.	50-70 yrs.*	*	Longest to shortest optimum period Black spruce≧ white spruce > birch ≧ aspen ≧ poplar
Seed ripening	End of 1st to 2d week in Aug.	Early Sept.*	Maybe as early as July, but most common Aug. to Sept.*	June*	May or June*	Earliest to latest Poplar > aspen > birch ≧ white spruce > black spruce
Dispersal:						
Initial	Mid-Aug. to early Sept.	Sept.*	July to Sept.*	June*	Early June*	Earliest Latest Poplar > aspen > birch ≧ white spruce > black spruce
Duration	75-90 percent dispersed by Dec.	Throughout year*	90 percent by Dec.*	June-July*	June*	Longest Shortest Black spruce > white spruce ≧ birch > aspen ≧ poplar
Seed quantity (seeds per acre)	0 to 16 million	300,000 to 2 million*	2.2 to 300 million	Up to 200 million*	*	Largest Smallest Aspen ≧ poplar ≧ birch > white spruce > black spruce
Seed quality (percent of total crop)	6-70 percent (average, 45 percent)	7-86 percent (average, 47 percent)	1-42 percent (average, 17 percent)	Maybe very high (98 percent) viability of short duration under natural conditions*	*	Birch ≧ aspen ≧ poplar > white spruce > black spruce
Dispersal distance	150-200 ft. (2 tree heights)	2-3 tree heights*	At least 2 to 3 tree heights*	Long distance*	*	Farthest Shortest Aspen ≧ poplar > birch ≧ white spruce > black spruce
Periodicity of maximum seed crops	10-12 yrs.	Every 4-6 yrs.*	2-4 yrs.	4-5 yrs.*	Large quantities every year*	Most frequent Least frequent Aspen ≧ poplar ≧ birch > black spruce > white spruce
Viable seed-seedling ratio:						
Mineral soil	At least 12 to 24	3*	20-400*	Probably many thousands*	Approaching many thousands*	Least Most White spruce ≧ black spruce > birch > aspen ≧ poplar
Organic matter[1]	800 to 1,000*	100*	400+*	Impossible*	Impossible*	Least Most White spruce ≧ black spruce > birch > aspen ≧ poplar
Seedbed requirements (i.e., believed most optimal under Alaska conditions)	Mineral soil	Mineral soil	Mineral soil*	Mineral soil*	Mineral soil*	
Vegetative reproduction:						
Type	Adventitious shoots*	Layering, adventitious shoots	Sprouting of dormant buds	Root suckers	Root suckers	
Capacity	Rare*	Common under disturbed conditions but of doubtful importance in burns*	Common under some conditions*	Very common in fire-killed aspen stands	Common*	Aspen ≧ poplar > birch > black spruce > white spruce

*Variables for which no Alaska data are available.

[1] *Thickness of organic layers generally less than 2-3 inches except in black spruce where the data were derived from studies on organic soils.*

contribute to this species' success in colonizing burned areas. Some mature cones remain closed, requiring heat for opening. Jack pine cones tend to be clustered in the tree crowns so that only intensive crown fires would cause destruction of the seed source of mature trees. Ahlgren (1970) reported that the major seed source was provided from cones 2-4 years old, as these cones are more numerous and contain seed of higher viability than cones of other age classes.

Until the mid-1930's, it was thought that jack pine was capable of reseeding cut-over areas without the aid of special techniques such as fire or seedbed preparation. At that time, results from studies primarily concerned with the reseeding abilities of red and white pine on logged areas also brought the seeding requirements of jack pine to the attention of foresters. Basic observations indicated that jack pine reproduction did not successfully occur unless fire had also occurred at a particular site (Eyre, 1938). Closer study revealed that the destruction of litter, preferably the exposure of mineral soil, and stimulation by heat for the opening of mature cones, were beneficial results of fire affecting the reseeding ability of jack pine. The role of fire in exposing mineral soil is probably the most important function. Since that time, the use of prescribed burning techniques for the purpose of jack pine regeneration has been investigated extensively (Ahlgren, 1970 and Cayford, 1970).

Table 3. Jack pine germination and seedling survival on 30 10-square meter plots of each study tract for 5 years following prescribed burning and wildfire. (From Ahlgren, 1970)

		Bearskin Lake seed tree burn tract				
Postfire years	1	2	3	4	5	Total
First year germinants	24	74	13	1	30	142
Older seedlings	..	13	70	62	62	...
Total seedlings	24	87	83	63	92	92
Survival, percent*	..	54	80	75	98	65†
		Grass Lake burn tract, hand seeded				
First year germinants	60	97	14	0	0	171
Older seedlings	..	49	145	145	140	...
Total seedlings	60	146	159	145	140	140
Survival, percent*	..	82	99	91	96	82†
		Keeley Creek wildfire tract				
First year germinants	588	356	44	8	0	996
Older seedlings	..	253	406	432	385	...
Total seedlings	588	609	450	440	385	385
Survival, percent*	..	43	67	96	88	39†

* Survival percentage was computed from the number of total seedlings of the preceding year and the older seedlings of the current year.

† Total survival was computed from the sum of all first year germinations and final total seedlings.

Table 4. Dominant herb and shrub species on study tracts. (From Ahlgren, 1970)

Species	Preburn Average cover, percent	Preburn Average height, feet	Postfire Average cover, percent Year 1	Year 2	Year 5	Postfire Average height, feet
		Bearskin Lake seed tree burn tract				
Aster macrophyllus	80	0.6	58	79	22	0.4
Pteridium aquilinum	51	3.1	43	53	33	1.8
Oryzopsis asperifolia	2	0.7	1	2	10	0.8
Corylus cornuta	53	5.6	3	3	10	1.2
Vaccinium angustifolium	3	0.8	1	1	13	0.7
Comptonia peregrina	1	1.2	1	1	18	1.5
		Bearskin Lake cut unburned tract				
Aster macrophyllus	81	0.6	76	83	32	0.4
Pteridium aquilinum	34	2.7	4	13	16	1.9
Oryzopsis asperifolia	3	0.6	3	13	21	0.9
Corylus cornuta	55	5.4	31	20	14	3.0
Vaccinium angustifolium	3	1.2	2	6	11	0.8
Amelanchier sp.	3	4.9	2	2	4	2.5
		Grass Lake burn tract, hand seeded				
Aster macrophyllus	83	0.8	3	27	57	0.6
Pteridium aquilinum	34	2.2	14	35	35	1.6
Carex spp.	..	..	2	87	54	1.1
Corylus cornuta	49	6.4	1	1	5	1.2
Vaccinium angustifolium	4	1.2	1	1	2	0.6
Alnus crispa	13	6.0	1	1	2	1.9
		Dragon Lake burn tract, hand seeded				
Aster macrophyllus	83	0.6	67	53	..	0.4
Pteridium aquilinum	36	2.5	47	17	..	1.1
Oryzopsis asperifolia	4	0.5	4	7	..	0.6
Corylus cornuta	48	5.1	14	18	..	1.5
Vaccinium angustifolium	9	1.1	6	11	..	0.6
Diervilla Lonicera	1	1.1	2	2	..	0.9
		Keeley Creek wildlife tract				
Aster macrophyllus	..	..	4	5	5	0.4
Carex spp.	..	..	1	9	16	1.8
Epilobium angustifolium	..	..	0	1	29	2.7
Comptonia peregrina	..	..	0	1	5	1.4
Vaccinium angustifolium	..	..	1	1	8	0.5
Diervilla Lonicera	..	..	1	1	2	1.1

Ahlgren (1970) reported that jack pine became established on burned tracts within 2 years following fire on both wildfire and prescribed burn areas (Table 3) and that the reduced soil surface moisture content did not appear to critically affect germination and seedling survival except in times of drought. Herbaceous plants provide the dominant ground cover after fire, the density of some species gradually lessening 3-5 years after the fire (Table 4). Germination and seedling survival of jack pine thus can occur beneath ground cover of herbaceous plants, the seedlings grown in association with species such as *Aster macrophyllus, Pteridium aquilinum*, *Epilobium angustifolium*, and *Carex* spp. Fire temperatures of sufficient intensity to severely damage the root collars of shrubs cause a reduction of shrub cover the first few years following fire (Table 4). By the time shrub growth and cover begin noticeably increasing, tree growth has progressed so that the young trees begin to rise above the shrub layer. Light fires or cutting without burning generally stimulate shrub growth and retard or prevent tree growth.

The botanical range of jack pine in Minnesota extends throughout the coniferous region, reaching its southern limit in Anoka county, with occasional outlying stands in southeastern Minnesota. In the southern part of the range, the closed-cone character may give way to more open-type cones. Rudolph, *et*. *al*. (1937) suggested that the geographical distribution of these cone types may have been influenced by forest fire patterns. Ahlgren (1960) found that, 5 to 7 years following germination of jack pine seed from scorched cones on burned land, the seedlings were producing seeds of 80 percent viability. Young trees that had been planted on burned-over sites were producing more cones at an earlier date than seedlings of jack pine of the same ages that had been planted nearby on unburned land. The presence of as few as 7 to 10 mature dominant jack pine trees per acre can insure reestablishment of the species on a burned area (Ahlgren, 1960, 1970).

C. White pine (Pinus strobus) and red pine (P. resinosa)

The presence of even-aged stands of red pine and of white pine established after forest fires is well acknowledged in the literature (Maissurow, 1935, 1971; LeBarron, 1939; Heinselman, 1969, 1971). The thick bark and tall, clear trunks of older representatives of these species provide some protection against fire. Results of experimental fires in red pine and white pine stands suggest that pine maintains maximum flammability up to heights of about 60 feet, and thereafter the possibility of crown fire is lessened by the increasing height of the open trunk space (Van Wagner, 1970). Crown scorch is probably the limiting factor in survival of the taller red and white pine from hot surface fires.

White and red pine shed their seed annually and produce good seed crops every 4 to 5 years. For these species to reestablish on burned land, it is imperative that individual seed-bearing trees escape the destruction of fire.

As old white pine stands thin out, seedlings often become established in the natural openings; at least this appears to have been a pattern characteristic of such stands before effective fire protection beginning about 1930. During the 1940's observers were of mixed opinion regarding the effects of surface fire on red and white pine regeneration. In some cases surface fire was regarded as a negative factor (Eyre and Tehngraff, 1948). Other observers stated that surface fire was necessary as a clearing agent (Eyre and LeBarron, 1944). Heinselman (1973) found that the average interval between fires in red and white pine stands where some or all trees survived was 36 yr, ranging from 5 to 100 yr. According to recent data from the BWCA (Ohmann and Ream, 1971), fire protection in mature red and white pine stands has resulted in an understory of balsam fir and/or spruce.

Germination and seedling development are generally favored by exposed mineral soil or a seedbed with a light duff layer. Stands tend to be located in areas which are protected from frequent fires, such as islands and the shores of larger lakes. It is possible that red pine is more limited to naturally protected areas than is white pine (Van Wagner, 1970; Ohmann and Ream, 1971). White pine is generally much more successful under a canopy than is red pine, perhaps due to the nature of the light requirements of the two species (Logan, 1966). The quantity and quality of light affects parameters such as air and soil temperatures, soil moisture, and root competition.

Red pine is dependent on fire at certain stages in its life cycle, yet is quite susceptable to fire damage and destruction. The relationship between fire and red pine is perhaps the most delicate of any tree species of the northern coniferous forest. Regarding this relationship, Van Wagner (1970, p. 216) stated the following:

> "The picture of red pine ... is of a species that depends heavily on fire because of its silvics but has evolved very little in any way that takes positive advantage of fire. The physical features that distinguish red pine from most other tree species with respect to fire are the flammability of its stands, and its relatively resistant bark. And yet the very flammability that invites the necessary fire also works against red pine, since it is very liable to total destruction before the age (about 50) at which it produces appreciable seed and has a fairly protective bark."

The age and composition of red and white pine stands are thus related to fire. The presence or absence of periodic ground fire helps determine the composition of the understory from which develops the future canopy. New stands are introduced by fires which are severe enough to clear away sufficient cover. The age of the understory class or classes in red and white pine stands usually date back to fires. Large, even-aged stands are common in the BWCA. Many stands have two or more overstory age classes which originated from separate fires.

As stated above, most red and white pine stands originate from fire. If a second major burn occurs before the trees reach seed-bearing age, these species may be virtually eliminated from the area. Heinselman (1973) cites examples of this in the BWCA. Allowing ground fires in appropriate areas would reduce the danger to the dwindling numbers of red and white pine in the BWCA.

D. Black spruce (<u>Picea</u> <u>mariana</u>)

Mature black spruce stands are easily killed by fire, as the presence of dead branches on lower trunk levels make the trees very susceptible to crown fires. A characteristic of this species which enables prompt reseeding after fires is that the serotinous cones may retain seed for many years and the cones being induced to open by heat (LeBarron, 1939). Viable seed from 15-year-old cones has been reported (Heinselman, 1957). Most stands produce a regular seed crop after 25 years. Seed dispersal occurs throughout the 12 months following maturation, although in some instances seed may be retained longer.

LeBarron (1948), working near Ely, Minnesota, found that total seed crop failures are infrequent, and failures for as many as 2 or 3 successive seasons are rare. Heavy seed crops occur about once every 4 years (Heinselman, 1957). As with jack pine, the exposure of mineral soil is advantageous to the survival of the tiny seedlings (Ahlgren, 1959). Black spruce stands which were established on burned land are usually of higher quality than stands established by other means (LeBarron, 1949; Millar, 1939).

Thus black spruce, despite the flammability of individual trees, is a successful fire-following species of the northern forests. The production of seed at an early age, the frequent seed production, the serotinous nature of the cones, and the preference of mineral soil for establishment of growth are some characteristics which insure the importance of the species in a fire-frequented environment.

E. White spruce (Picea glauca)

Like black spruce, white spruce is easily burned. Thin bark and the presence of branches near the ground make the aerial portions of the tree very susceptible to burning. Slowly burning, hot surface fires are capable of destroying the shallow root system. In the interior of Alaska, Lutz (1956) observed that living white spruce with fire scars were uncommon and, if present, were almost invariably located at the edge of burns where fire intensity was low.

The cones of white spruce open after seed ripening with 75 to 90 per cent of the seed crop being released within 3-4 months (Zasada and Viereck, 1970). A small amount of viable seed may be retained for at least a year. Quantities of wind-borne seed adequate for restocking are generally not found further than 150-200 feet beyond the seed source (Zasada and Gregory, 1969). Regeneration after a severe fire would have to depend on a nearby seed source relatively undamaged by fire. .. Optimum seed production in natural stands of white spruce begins at 40 to 60 years of age (Rowe, 1955; Zasada and Gregory, 1969). While data concerning frequency of optimum seed crop production in northern Minnesota are not available, it is probable that such production in white spruce occurs less frequently than in black spruce (Zasada, 1971). Seed crop failures are observed periodically in white spruce. Lutz (1956) cited a reference by Hesselman on the relationship of forest fires and heavy seed crop years of Norway spruce in Sweden - that warm summers enhance the occurrance of forest fires and of optimum seed production. In a literature review pertaining to white spruce, Zasada and Gregory (1969) cite numerous references stating that warm temperatures enhance various stages of seed development, provided drought is not a significant factor. The characteristics of white spruce which seemingly place it at a disadvantage regarding natural reforestation following fire might be somewhat compensated for by the timely occurrance of seed years.

White spruce, like black spruce, is able to survive in the understory and to compete with the overstory trees (Lutz, 1956; Ohmann and Ream, 1971). Yet both species reproduce well on bare mineral soil, and grow well in full sunlight. In Manitoba, Bedell (1956) reported that spruce regeneration is not readily established on a heavy layer of litter and humus, but will do so on exposed mineral soil. He quoted unpublished data of Tunsell which concluded that white spruce produced well only on burned areas. Similar observations were reported by Millar (1939) in northern Ontario.

F. Quaking aspen (*Populus tremuloides*)

This species is a shade-intolerant pioneer species which characteristically develops in even-aged stands. The trees are killed by hot fires, but in pure stands the accumulation of forest floor material is usually too light to support a hot, persistent fire (Lutz, 1956). Perhaps the most well-known characteristic of aspen is the prolific reproduction by means of root suckering, especially following a disturbance such as wildfire. In the interior of Alaska, Lutz (1956) observed as many as 80 3-year-old suckers per milacre under one fire-killed aspen.

Observations following a wildfire near Petawawa, Ontario, indicate that a moderate degree of burning, in which the tree canopy and undergrowth are killed, litter is eliminated and duff is reduced, will most effectively stimulate suckering (Horton and Hopkins, 1965). The areas of the burn classified as low-intensity were characterized by incomplete destruction (one half or more) of the canopy trees and resprouting of burned underbrush.

The results are shown in Table 5. Suckers were abundant on both burn conditions, but their density and growth were significantly greater on the areas of the moderate burn. The rolling, sandy terrain covered by the burn was covered by a dense stand of 25-year-old aspen prior to the fire. The number of stump and root collar sprouts was low because of scorching of the parent stems.

Table 5. Comparison of year-old aspen reproduction on light and moderate burns. Based on a sample of 100 milliacre quadrats in each condition. (From Horton and Hopkins, 1965)

	Root Suckers		Stump & Coller Sprouts	
	Light Burn	Moderate Burn	Light Burn	Moderate Burn
No. of quadrats stocked to 1+ stems	92++	97	32++	26
Total no. of stems	800*	1323	229++	189
Average ht. (ft) of tallest stem	2.8**	3.3	2.6++	2.4

*Significant, **highly significant, ++non-significant by range test

Aspen roots from one-half-inch depth to several inches below the soil surface provide a protected source for root suckers. Horton and Hopkins (1965) found that the insulation of half an inch of fine sand was sufficient to protect roots against a few minutes of sustained high surface temperatures. Increasing the soil moisture content directly increased protection of the roots from surface heat. The results of studies by Miani and Horton (1966) suggest that it is the total soil-warming effect of removal of cover which stimulates suckering. Repeated burning is often detrimental to reproduction by suckering (Lutz, 1956).

In addition to vegetative reproduction, aspen produces large quantities of seed, the period of optimum seed production being 50 to 70 years-of-age. The seeds are equipped with long hairs which enable the seed to be dispersed over relatively long distances. The seeds are dispersed within a few days of ripening (Strothman and Zasada, 1957). Seed viability is of short duration, but the possible dispersal distance may make reseeding possible over a larger area than that by many other tree species. Germination and survival of young seedlings seem to require mineral soil for best results.

G. Paper birch (Betula papyrifera)

Trees of this species are very susceptible to burning, but the shallow forest floor under birch trees and stands is usually incapable of supporting a hot, persistent fire. Lutz (1956) observed that regeneration by sprouting from root collars of fire-killed young birch was frequent, but such reproduction was not commonly found in older stands. Paper birch is recognized as a pioneer species of the northern coniferous forest. Regeneration on burned lands often results in paper birch stands of high quality. Mineral soil seedbeds and full sunlight are preferred by the species for germination and seedling survival. Ahlgren (1959) reported successful germination only on moist sites. Reproduction by seed is more important than that by vegetative means. Seed production is high, but the seed is of lower viability compared to other species with which it may be associated (Zasada, 1971). Late summer fires would coincide with availability of seed from any nearby seed source.

H. Other species

Tamarack (Larix laricina) may be a pioneer species following fire, although the moist to boggy habitat where this species is usually found is not subject to fires except under conditions of exceptional drought. Balsam fir (Abies balsamea), a shade tolerant species, may develop as a significant component of the understory growth as a result of the exclusion of surface fires. Balsam fir is not adapted to fire survival as are conifer species such as those previously discussed. This species is generally found in moist areas. Northern white cedar (Thuja occidentalis L.), as the dominant species is usually found only on relatively moist cool areas. Its presence in any abundance usually indicates sites that have been subjected to fire much less frequently than other areas of the northern forests. The moisture requirements of balsam fir and white cedar are higher than those of the successful fire-following conifer species. Tamarack, while possessing high moisture requirements, may also be a fire-following pioneer species.

Balsam poplar (Populus balsamifera L.), native to but found infrequently in northeastern Minnesota, is a pioneer on burned lands in other regions. In Alaska, Lutz (1956) observed that "... the occurrence of balsam poplar in anything approaching pure stands on upland areas is practically contingent on the occurrence of fires" (p. 26). Like aspen, balsam poplar regenerates by root suckers following fire in stands of the species, produces abundant wind-disseminated seeds, and is shade-intolerant.

IV. EFFECTS OF FOREST FIRES ON VEGETATIONAL DEVELOPMENT

Forest fires may affect vegetational development in various ways, two critical factors being the soil type and the available seed supply. The nature of a fire itself also affects the future plant cover, as different types of fires result in different conditions. A crown fire may destroy everything in its path, creating conditions favorable for the establishment of fire following pioneer species such as quaking aspen or jack pine. Such events delay the succession to the climax forest by establishing a cover type that is an early seral stage in terms of succession. As mentioned above, the soil type and the species available for restocking a burn are critical variables. In some cases the results could be such that climax species (e.g., white spruce and balsam fir) may seed in on a fresh burn, thus hastening the development of a climax cover type. Ground or surface fires in most cases would delay succession. Such fires often clean out the understory and thus perpetuate the life of the stand. A well developed understory is a fire hazard in stands of large trees. Shade-tolerant, climax species mostly compose the understory.

Thus there are several variables to consider in discussing the effects of forest fires upon succession. Results vary in that succession may be either hastened or slowed in terms of developing a climax forest type. Lutz (1956) indicated that succession after fire is a blend of chance and order:

> Forest vegetation development following fires in the interior of Alaska is neither a completely fortuitous, random process nor is it an invariable, highly ordered process closely directed by a mysterious beneficient "Nature." Elements of the fortuitous do exist but there are also elements of order.

This statement also could be applied in consideration of northeastern Minnesota.

As previously mentioned, an all-consuming blaze may produce a burn that becomes populated by fire-following species. Several characteristics separate pioneer species from those which represent more advanced seral stages (Lutz, 1956). Post-fire stands are often composed of tree species different from those existing at the time of the fire. Climax vegetation tends to be replaced by pioneer species, the latter representing early successional stages. Tree species are less numerous in new stands. Pioneer species are often shorter-lived and less shade tolerant than species of later seral stages. Abundant production of light, easily disseminated seeds or prolific vegetative reproduction favor the entry of pioneer species into burned sites.

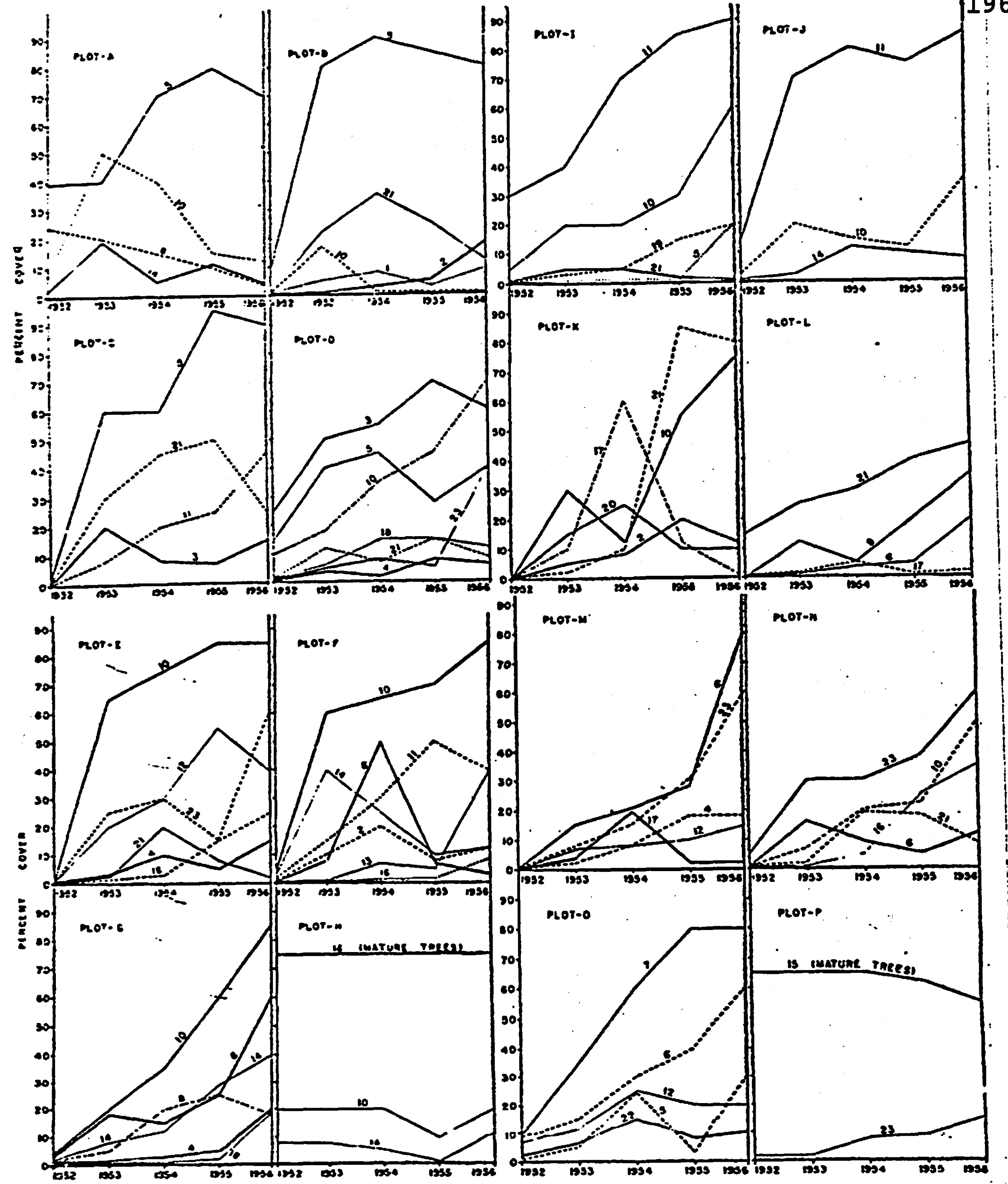
Several hypotheses exist regarding the climax cover type of northeastern Minnesota. Ohmann and Ream (1971) suggested that the dominant climax species in upland areas of the BWCA would be white spruce, black spruce, and balsam fir, with lesser numbers of paper birch, red maple, red oak, white cedar, and white pine.

As mentioned above, fire can either hasten or delay

Plot	A	D	F	G	B	C	K	L	M	N	E	J	I	O	P	H
Pre-fire forest	jack pine				spruce-fir			8 year jack pine plantation	black spruce			aspen		tamarack bog	black spruce	jack pine
Burn intensity	hard	severe	hard	light	hard	severe	hard	hard	hard	severe	hard	hard		hard	unburned	
Post-fire organic layer	1 in.	2 in.	1 in.	2 in.	1 in.	2 in.	2 in.	1 in.	3 in.	6 in.	3 in.	1 in.	3 in.	3 in.	2 in.	2 in.

Table 6. Site history for the 16 sets of 3 concentric plots. (From Ahlgren, 1960)

FIG. 5. Graph giving the per cent cover for 5 yr. on the 1/1000 acre plots. The number given above the plotted lines refers to the individual species given on that line. 1. *Amelanchier* sp.; 2. *Aralia nudicalis*; 3. *Aster macrophyllus*; 4. *Betula papyrifera*; 5. *Calamagrostis canadensis*; 6. *Carex* spp.; 7. *Chamaedaphne calyculata*; 8. *Clintonia borealis*; 9. *Comptonia peregrina*; 10. *Cornus canadensis*; 11. *Corylus cornuta*; 12. *Ledum groenlandicum*; 13. *Linnaea borealis*; 14. *Maianthemum canadense*; 15. *Picea mariana*; 16. *Pinus banksiana*; 17. *Polygonum cilinode*; 18. *Prunus pensylvanica*; 19. *Populus tremuloides*; 20. *Ribes glandulosum*; 21. *Rubus idaeus*; 22. *Salix* sp.; 23. *Vaccinium angustifolium*. (From Ahlgren, 1960)



the development of the climax cover type. In a mature red or white pine stand, ground fires delay succession by eliminating the understory of balsam fir, spruce, and red maple. If a spruce stand became established on the site of a burned red or white pine grove, then the seral stage in this case would be advanced toward the climax vegetation.

Ahlgren (1960) reported 5-year changes in vegetation cover on 1/1000 acre plots established in 16 study areas representing various forest communities found in the Superior National Forest. Site history for the 16 sets of plots is given in Table 6. Intensities of burn are classified as follows: 1) light burns consumed only loose litter, with slight scorching of crown foliage; 2) hard burns consumed all litter and some duff, tree crowns killed by scorching; 3) severe burns consumed all litter, duff, and some humus. Figure 5 gives the changes in per cent cover for 5 years for the major species on each of the plots. Tree species which reproduce by root sprouting as well as by seed did not increase as rapidly as might have been expected, possibly due to heat damage of the roots. Shrubs were slow in regeneration on hard and severely burned plots. Herbaceous species usually showed much increase in per cent cover after 3 or 4 years.

Another portion of this study (Ahlgren, 1960) involved catagorizing plants into those occurring on 1) unburned land only; 2) burned land only; and 3) burned and unburned land.

Table 7. Frequency of species by series. Figures given in the table represent the percent of plots out of each 30-plot series in which the species was found. S refers to seed origin, V to vegetative origin, V-S to vegetative and seed origin in about equal numbers. The small letter in parenthesis indicates the less frequent method of reproduction. (From Ahlgren, 1960)

Location	Heart Lake				Keeley Creek			Tomahawk Road	Plum Lake		Polly Lake	
Burn intensity	Hard		Severe	Unburned	Severe		Unburned	Light			Hard	
Moisture	Well drained		Moist	Well drained	Moist		Well drained	Well drained			Variable	
Series	1	2	3	4	5	6	11	7	8	9	10	Type of reproduction and dispersal agents
Class-A Unburned Land Only												
Cypripedium acaule				10			13					
Cinna latifolia				3			7					
Goodyera repens				20			10					
Polypodium virginianum				7			13					
Class-B Burned Land Only												
Geranium Bicknellii	3	7	10		100	100		47	23		3	S—small mammals
Epilobium angustifolium	7	3	97		87	100		10	3		87	S—small mammals, wind
Epilobium glanduloseum	3	3	7		60	93						S—small mammals, wind
Marchantia polymorpha					80	93				23	43	spore—wind
Corydalis sempervirens	3				50	43		17				S—gravity
Dryopteris spinulosa	3		33			3						V
Carex disperma	7	7	60									V (s)
Viola incognita	20		43									S (v)—song birds
Lonicera canadensis	7	7						13	40	47		V
Polygonum cilinode	73	80	97		83	57		47	3	7	30	S (v)—small mammals, song birds
Anaphalis margaritacea	7		13		17	7		7	7		33	S—gravity, wind
Aralia hispida	7	13	43		30	23		30	17	3	80	V-S—small mammals, song birds
Aster ciliolatus	27	7								10	53	V-S—small mammals, wind
Anemone quinquefolia	30	77	20		50	23		60	27	63		V-S—gravity
Comptonia peregrina	23	53	10		63	73						S—deer
Carex sp.	53	30	63		93	93		93	93	83	73	V (s)
Class-C Burned & Unburned Land												
Cornus canadensis	100	90	97	90	87	67	93	97	100	100	90	V (s)—small mammals, song birds
Maianthemum canadense	40	100	40	93	70	47	90	87	100	100	40	V (s)—small mammals, grouse
Vaccinium angustifolium	93	100	97	97	63	63	93	87	73	97	90	V (s)—small mammals, birds, bear
Clintonia borealis	80	57	37	73	47	27	70	87	87	73	30	V (s)
Lycopodium obscurum	23	13	3	23		3	17	17	3	30	23	V
Aster macrophyllus	77	87	73	30	60	27	23	73	97	100	43	V (s)—small mammals, wind
Rubus idaeus	93	97	100	20	70	40	17	97	20	57	83	V-S—small mammals, birds, bear
Rubus pubescens	77	50	17	37	77	20	40	87	97	97	17	V-S—small mammals, birds, bear
Viola spp.	7			7	3	3	3	37	23	47	73	S (v)—small mammals, song birds
Alnus crispa	30	37	43	23		3	17	83	83	17	63	V
Ribes glandulosum	20	7	30	7		3	3	17			63	S—small mammals, song birds
Pinus Banksiana	33	90	50	37*	97	93	40*	40	7	23	93	S—wind
Betula papyrifera	13	20	97	20*	83	100	13*	73	93	80	17	V-S—wind
Fragaria vesca	33	30	10	3	3	3		10		7	13	V-S—small mammals, song birds, grouse
Pyrus americana	27	17	20	67		7	73	40	3	13		V-S—song birds, grouse
Aralia nudicaulis	47	57	40	67	40	30	63	87	90	73	17	V (s)
Gaultheria hispidula	3		67	20			17		13	7		V-S—small mammals
Populus tremuloides	23	7	30	10	77	80	10	33	3	17	70	V-S—wind
Dryopteris Thelypteris	3		33	7	17	20	10	13	10		3	V
Picea mariana	3	17	93	77	97	97	67		17	10	50	S—wind
Apocynum androsaemifolium	37	63		13	13		7	3	43	67	3	V-S—wind
Linnaea borealis	47	77	33	13	43	17	17	57	67	70		V
Oryzopsis asperifolia	77	100	10	33	50	20	37	80	47	87	33	V-S—gravity
Amelanchier sp.	60	73	13	33	10	13	30	27	50	57	23	V
Corylus cornuta	83	37	3	70	17		73	43	93	80	3	V (s)—small mammals
Diervilla Lonicera	100	93	33	50	30	20	53	93	100	97	87	V (s)
Trientalis borealis	10		3	7		3	7	13	33	40	13	V-S
Rosa acicularis	40	50	43	50	50	10	57	60	87	83	13	V (s)—small ammmals, song birds, grouse
Calamagrostis canadensis	93	100	67	33	83	37	30	83	30	23	67	V (s)—wind

* Mature trees included.

Results of this work are presented in Table 7, giving occurrence of these plants in the study series , their types of reproduction, and most frequent means of dispersal. Eleven series of 30 plots each were surveyed. Plants found only on unburned series were shade-tolerant perennials reproducing mainly by means of shallow or surface rhizomes or bulbs. The second group, found only on burned series, consisted mostly of seed-reproduced annuals plus some vegetatively-reproduced species which were probably in the area before the fires. Included in this group are such well-known fire-followers as cranes-bill (*Geranium bicknelli*) and fireweed (*Epilobium angustifolium*). The group of plants found on both burned and unburned series show tolerance of fire, since underground reproductive structures survived fire. This group is more representative of the characteristic ground cover of the area (Ahlgren, 1960). Ground vegetation is apparently not permanently influenced by fire, the most noticable results being the temporary existence of fire-following species on burned sites.

V. THE FUTURE OF VIRGIN FOREST COMMUNITIES OF THE BWCA AS RELATED TO CURRENT MANAGEMENT POLICIES.

In an extensive study of virgin upland plant communities in the Interior Zone of the BWCA, Ohmann and Ream (1971, p. 27) stated the following:

> We conclude that differences in the structure and composition of the plant communities of the virgin vegetation of the BWCA are primarily due to differences in the time elapsed since the last major wildfire disturbance and the composition of the vegetation present at the time of that disturbance. Thus we see major changes occurring in the plant communities due to the fire protection policy of the Forest Service.

A study is in progress to develop a system of quantitatively predicting percent composition of tree species in a stand 50 years into the future. Meanwhile, based on populations of tree species in three different size classes of "tree", "seedling", and "sapling", Ohmann and Ream (1971) have made qualitative predictions of succession. Black spruce will probably become dominant in the presently jack pine dominated communities, and also in the red pine community. Communities not already dominated by balsam fir, but where balsam fir is important, will apparently become dominated by balsam fir, paper birch, white spruce, and to a lesser extent black spruce. The lichen community will eventually give way to a black spruce-feather moss community with the advancing of soil development and occupation by higher plants.

Jack pine and quaking aspen are strictly pioneer species in the area, representing early seral stages that are particularly dependent upon fire for the perpetuation of the species. Both species will probably decrease greatly, given the current fire exclusion practices. Aspen stands will be succeeded by balsam fir with lesser numbers of black and white spruce. Red maple may comprise an intermediate stage between aspen and birch stands and the spruce-fir climax mixture.

Jack pine apparently will be succeeded by a variety of types, depending on soil parameters (Ohmann and Ream, 1971). Some jack pine-dominated communities show evidence of moving toward either hardwood or red and/or white pine stages preceeding the spruce-fir climax. Other stands apparently will be succeeded mostly by black spruce with balsam fir as a lesser component. Still other jack pine stands will be succeeded by black spruce, which may in turn give way to predominately balsam fir with lesser numbers of paper birch, red maple, black and white spruce, and red and white pine. Thus jack pine will probably give way to various mixtures of the spruce-fir climax and not propagate itself to any extent.

The understory in red and white pine stands consists mostly of climax species and poses a threat to such stands by presenting fuel to feed large fires which would destroy the canopy. Absence of ground fire allows fuel to build up for a potential conflaguration. Red and white pine are long-lived species and could be present for some time with proper management. White pine is more successful in an understory than is red pine, thus the former species may continue as a minor component in the BWCA with more success than the latter species (Ohmann and Ream, 1971). Sizable stands of any of the three pine species mentioned above may be eliminated with the near absence of fire. More advanced seral stages are replacing pine stands.

With the increase in balsam fir, spruce budworm (Choristoneura fumiferana Clem.) attacks may become more frequent. Fire suppression policies have the potential to create the very condition they were designed to prevent, as accumulation of organic matter could result in a disasterous conflaguration. Effects on wildlife populations would become apparent with the disappearance of aspen and red and white pine. Herbacious animals and birds, along with the associated prey species, would show reduced populations.

The above predictions are mostly hypotheses, based on facts. Nevertheless, to allow proof would be tragic.

VI. SUMMARY

Forest fire has been a natural component of the northeastern Minnesota area for thousands of years. As a result, the native vegetation shows adaptions which equip some species for survival and success in a fire-frequented environment. Repeated fires burned from intervals approximately 5 to 50 years, with sheltered areas being subjected to major burns as infrequently as every 300-400 years. The oldest age class of trees on most sites can be dated to the last major fire on that site. The composition of virgin plant communities of the BWCA show the influence of fire disturbance.

Regeneration after fire is rapid and extensive, as a lush herbaceous growth generally appears in the first post-fire growing season. Tree seedlings tend to appear after the establishment of herbaceous growth. Tree species rapidly gain dominance after a few growing seasons. Fluctuations in wildlife populations accompany the changing character of the vegetation cover.

Fire has maintained the stability of the forest mosaic by creating local disturbances which prevent the forests from becoming uniform in composition as a whole. In constant change lies the prevailing stability of the forest. A large forest area left to natural controls shows a mosaic pattern of richness and variation of community types. In the BWCA and other undisturbed areas, fire has acted as an agent to prevent succession to the climax stage.

The imposing of controls on factors of natural disturbance, particularly the policy and practice of fire control, is causing a shift in vegetational patterns, the results of which are speculative, unnatural, and potentially dangerous to many plant species, wildlife populations, and man himself.

Many problems are inherent in restoring fire to an ecosystem such as the BWCA (Heinselman, 1973). Human safety and private and commercial property interests of surrounding areas are involved. Mechanical disruption of the landscape is certainly undesirable. Topographical features and certain plant communities create firebreaks which could be used in prescribed burning or control of wildfire. Aerial equipment offers easy access without disrupting the forest floor. Objections have been raised to possible air and water pollution factors being increased by debris from forest fire. The extent of possible pollution factors has not been quantitatively determined, but available data suggest that pollution would probably not be a valid basis on which to consider rejection of sensible prescribed fire management techniques. Studies of water enrichment following fire are being conducted in the Little Sioux burn area. Sando (1970) reported that the contributions to air pollution from all the prescribed burning (15,000 acres) in the lake states during the 1968 season was approximately equal to the effluents from automobile gas consumption in a 3 day period in the twin cities of Minneapolis-St. Paul.

Public opinion presents no small barrier to the use of fire as a management tool. In Sequoia-King's Canyon

National Park, where a long period of fire suppression resulted in undergrowth treatening the survival of ancient Sequoia trees, prescribed burning is now used as part of normal management procedures (Kilgore, 1970). Public reaction there is generally favorable, once the reasons for such actions are explained. The general populace has been misinformed for generations regarding the importance of fire as part of the natural system of checks and balances.

VII. CONCLUSION

Scientific awareness and interest in fire as a natural ecological force has greatly increased in recent years. In these developments lie great potential for both achievements and disaster. Any use of fire to manipulate an ecosystem can only be permitted after the most deliberate and cautious preliminary study and planning.

It appears that the controlled use of fire to maintain the forest mosaic of the BWCA in the condition resembling that which has been established over thousands of years is the only method that is consistent with the basic ecological principles of that region.

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